FIRST INSTALLATION OF SELECTIVE NON-CATALYTIC NOX REDUCTION PROCESS ON UTILITY BOILERS IN KOREA

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ABSTRACT

In September 1999, the Selective Non-Catalytic Reduction (SNCR) Process using urea began its operation on two 250 MWe coal-fired boilers at Korea Electric Power Corporation's (KEPCO) Honam Power Plant in Yosu, Korea. This is the first post combustion NOx control installation on a utility boiler in Korea. The urea SNCR process was selected considering the boiler life, available space for retrofit, balance of plant impact, and the process economics. From a nominal baseline NOx of 400 ppm corrected to 6% O_2, 40% reduction was required with less than 15 ppm NH3 slip at the economizer outlet. Units #1 and #2 are essentially identical, opposing-wall-fired units made by Babcock and Wilcox. Originally designed to fire oil, these units were converted to fire low sulfur (<0.5%) coal.

The SNCR system design included boiler measurements and computer modeling. Flue gas temperatures and species concentrations were measured at three different loads for both units. Based on these data, computational fluid dynamics modeling (CFD) and chemical kinetic modeling (CKM) of the units were completed to determine the optimum injector locations and other equipment requirements. Three independent levels of injection were specified with two levels of wall-mounted injectors in the upper furnace and one level of four multi-nozzle lances located within the superheaters.

The installed SNCR system satisfied all the requirements and was accepted by the plant in September 1999. The installation, start-up and optimization, and the first performance test were completed between May and September of 1999. As required by the contract, the second performance test was completed in April 2000, and once again all the requirements were met. NOx emissions have been consistently controlled during the past two years and no evidence of pressure drop across the air heater has been found during this time.

INTRODUCTION

In Korea, the national NOx emission limit for coal-fired utility boilers is 350 ppm corrected to 6% O_2. However, several special regions have been designated where more stringent NOx limits are promulgated. The coal-fired boilers at Honam Station exceeded both the more stringent regional limit of 300 ppm corrected to 6% O_2 as well as the national limit. After failing the annual emission test in October of 1997, the Korea Department of Environment ordered the Korea Electric Power Corporation, which is the owner and operator of Honam Station, to lower the NOx emissions. KEPCO initiated a study with the Korea Institute of Energy Research and Korea Heavy Industries Corporation (KHIC) to evaluate potential NOx reduction technologies applicable to the Honam Station units. The objective was to evaluate and recommend a technically capable NOx removal technology that is also the most economical.

The evaluation selected urea-based Selective Non-Catalytic Reduction (SNCR) as the most viable NOx control technology for Honam Station. SNCR was selected over low NOx burners and SCR because the plant had limited space for retrofit and less than 12 years of remaining life. SNCR offered the lowest capital investment and overall economics, required a shorter outage schedule, and was capable of achieving the NOx emission limit. Urea was selected over ammonia as the reagent of choice because it is easier and safer to handle, reacts effectively in a higher SNCR temperature window, and it is easier to distribute. Finally, the urea SNCR system has been installed on more utility boilers than the ammonia-based SNCR system. KEPCO awarded the project to KHIC as the general contractor. KHIC subcontracted Fuel Tech, Inc. to design, supply, start-up and optimize the urea SNCR process, and Aju System Co., LTD. to provide the urea solutionizer. KHIC installed the supplied equipment. The contract required 40% reduction from a baseline NOx of 400 ppm or higher, corrected to 6% O2, with less than 15 ppm of NH_3 slip at the economizer outlet. The urea consumption, expressed as a normalized stoichiometric ratio (NSR), was limited to 1.1.

UNIT DESCRIPTION

The Honam Station Units #1 and #2 are nominally identical, Babcock & Hitachi boilers, firing coal in a front and rear wall-fired arrangement at a maximum load of approximately 270 MW. Each boiler generates roughly 600-800 metric tons per hour of steam (depending on the fuel) at 160 kg/cm^2 at full load. The boilers were constructed in 1972 to fire #6 fuel oil, but were converted to fire coal in 1984 and 1985. Currently, low sulfur coals with less than 0.5% sulfur from Alaska, Australia, China, and Indonesia are used.

Each furnace is approximately 37 meters tall, from elevation 4200 mm to 41200 mm, with internal dimensions of 8.7 meters (front and back walls) by 14.8 meters (side walls). Three sets of a four-burner array are located on both the front and rear walls at elevations 11100 mm, 13500 mm, and 15900 mm. Mills in operation vary with the load. The furnace bull nose is approximately at elevation 31000 mm. Platen superheaters are suspended in the upper furnace above this elevation with a spacing of 1232 mm. The platens are followed by secondary superheater tubes and screen tubes. After the screen tubes, the gas flow splits into two ducts, each containing additional heat exchange surfaces. The reheaters are in the horizontal section of each duct. The gas turns downward and passes through the primary superheaters and economizers.

UREA SNCR PROCESS DESCRIPTION

Urea SNCR is a post-combustion NOx reduction method that is applied through the controlled injection of urea reagent into the combustion gas path of fossil-fired boilers, furnaces, incinerators or heaters. A typically used 50% urea solution can be prepared from solid urea prills through an on-site urea solutionizer or delivered as a solution. Based on the original research on the use of urea for NOx control developed under the sponsorship of the Electric Power Research Institute (EPRI), Fuel Tech, Inc. has further researched, developed, and applied this technology to units ranging in size from small to large and firing many different types of fuel. The proprietary knowledge, experience, and process know-how obtained by Fuel Tech during the past 15 years associated with this technology is marketed as NOxOUT® Process. The predominant urea SNCR reaction is described as:

$$CO(NH_2)_2 + 2\ NO + 1/2\ O_2 \Rightarrow 2\ N_2 + CO_2 + 2\ H_2O$$

Urea + Nitrogen Oxide + Oxygen = Nitrogen + Carbon Dioxide + Water

Though some trace quantities of ammonia and carbon monoxide may form, the quantities of these can be controlled.

Two key parameters that affect the process performance are flue gas temperature and reagent distribution. The NOx reducing reactions are temperature sensitive. By-product emissions can become significant at low temperatures while chemical utilization and NOx reduction decrease at excessively high temperature. The optimum temperature range is specific to each application. The reagent needs to be distributed within this optimum temperature zone to obtain the best performance.

PROCESS DESIGN

The SNCR system design was based on the understanding of the specific application, derived from field measurements and the simulation of the flue gas flow and temperatures through computational fluid dynamics (CFD) modeling. The chemical kinetics model (CKM) predicted the reaction of urea and NOx in the flue gas based on the temperature and flow information from the CFD model. These results, combined with the output of the Fuel Tech proprietary injection model, were used to determine the optimum temperature region and injection strategy. The multi-level injection strategy was programmed to adjust automatically to temperature and load fluctuations through control of the liquid pressure, reagent concentration, and the injection location.

In August 1998, a site survey was completed that included furnace temperature and species mapping. Boiler operating data and drawings were obtained and obstructions to potential injector and lance locations were identified. Flue gas temperatures were measured through existing observation ports using a water-cooled suction pyrometer at 50%, 70%, and 100% loads. Furnace flue gas was sampled and analyzed for CO, O_2, and NOx. At full load, the measured temperatures above the bullnose elevation ranged between 1050 and 1200 °C. Temperature decreased to 950~1100 °C at 70% and 850~1050 °C at 50% load. Furnace CO levels were less than 100 ppm except for a few ~300 ppm readings at full load.

CFD models were generated for the three cases corresponding to three loads (250 MW, 180 MW, and 130 MW). The computational domain for the CFD model begins at the furnace floor and ends beyond the economizer. Side sectional temperature profiles of the model results are shown in Figures 1-3, corresponding to the three loads, respectively. The model results are consistent with measured temperature data.

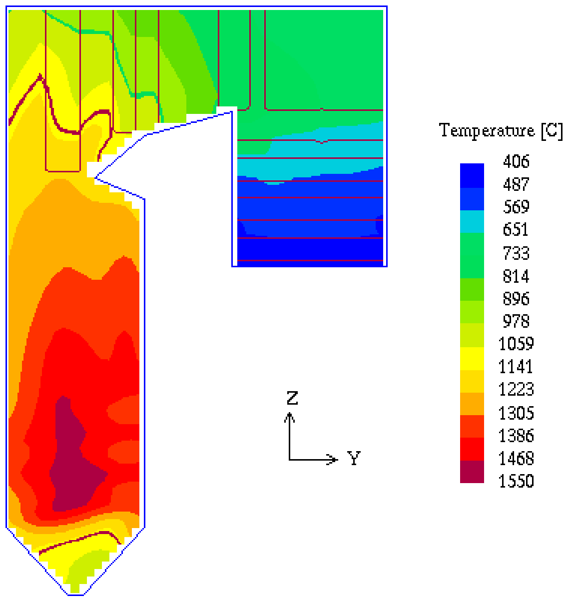

Figure 1. 250 MW

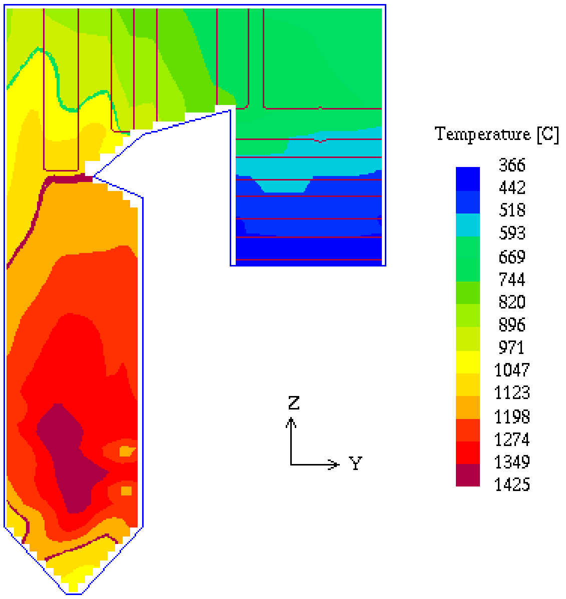

Figure 2. 180 MW

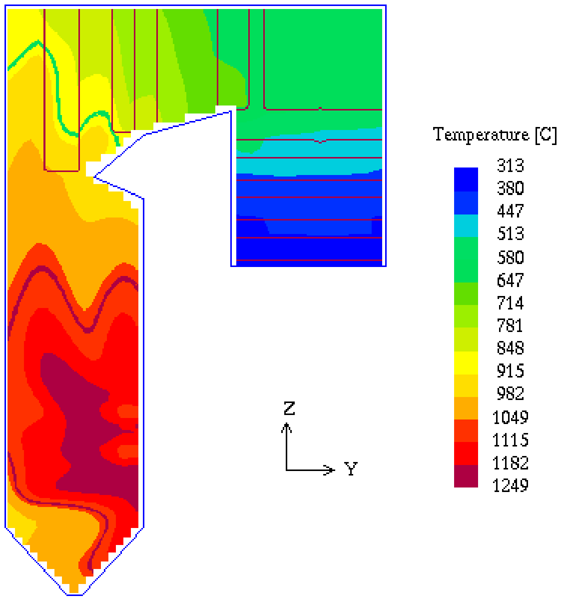

Figure 3. 130 MW

Achievable NO_x reduction is typically limited at low temperatures by ammonia slip and at high temperatures by competing reactions that convert the dissociated NH_3 to N_2 and H_2O or to additional NO_x prior to effective NO_x reduction. The identification of the process-specific temperature limits for desired NO_x control is an important result of CKM model. The CKM analysis at 250 MW indicated that the chemical should be released between 980 and 1125 °C in order to reduce NO_x by at least 40% while limiting NH_3 slip to less than 10 ppm. The lower temperature bound was dictated by the NH_3 slip limit, while the upper bound was dependent on the NO_x target. At 180 MW, CKM analysis showed that chemical release between 980 and 1125 °C was required to reduce NO_x by at least 40% while limiting NH_3 slip to less than 10 ppm. Finally, the 130 MW load condition required the chemical release at temperatures between 900-1075 °C.

Injection strategies were examined to identify scenarios providing the best opportunities for NO_x reduction. The chemical release windows for the three load conditions fall in different areas of the furnace as also shown in Figures 1 - 3. The red and green contours indicate the upper and lower temperature limits, respectively. As a result, three levels of injection were specified to cover the load range analyzed. The first level injector arrangement used fourteen injectors, with six injectors each on the front and back walls and one injector on each side-wall at 27000 mm elevation. The injector arrangement for the second level used a total of eight injectors, with six injectors located on the front wall and one on each side wall at 29500 mm. The highest zone used four multi-nozzle lances placed in the pendant superheater and secondary superheater at elevation 34490 mm. These locations are identified on Figure 4.

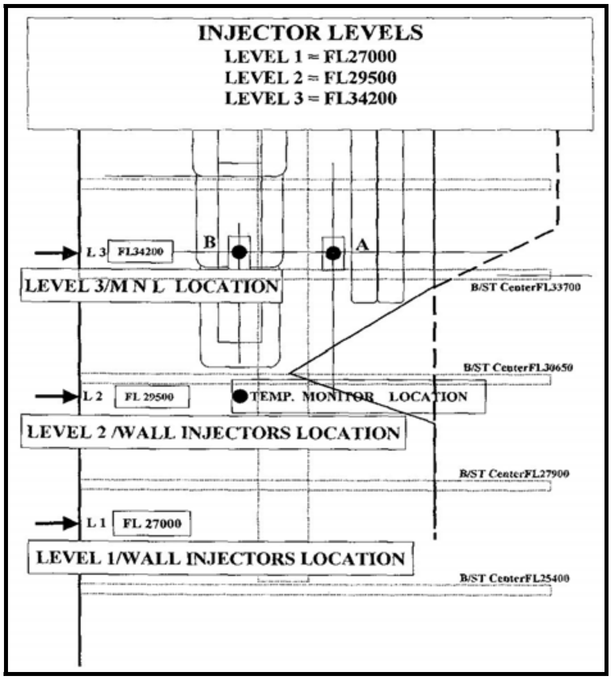

Figure 4. Injection Locations

EQUIPMENT DESCRIPTION

The SNCR equipment was designed and fabricated from October 1998 to March 1999. Installation began in April and was completed by the end of July 1999. The SNCR equipment layout is shown on Figure 5. A urea solutionizer with a 10 m^3 vessel prepares 50% urea solution several times a day, using steam as the heating medium. The solution is stored in two 140 m^3 tanks which are insulated and equipped with heating pads and a thermostat maintaining the temperature above 25°C.

The urea solution is pumped by a High Flow Delivery system (HFD) that feeds a circulation loop and supplies reagent to the Injector Zone Metering Modules (IZM) on both units. The HFD has an in-line heater to maintain the reagent temperature as well as a duplex strainer and two multistage stainless steel, centrifugal pumps to maintain the required head pressure.

The urea solution is diluted with water to provide sufficient mass for proper droplet formation and distribution. The dilution water is supplied on demand by the Dilution Water Pressure Control Module (DWP). The DWP is comprised of a duplex strainer, two multistage stainless steel pumps, and a pressure control valve.

The IZM is comprised of pressure and flow control valves, and it supplies the urea solution, diluted and mixed with water, to three independent levels of injection. Each wall injection zone

(Zones 1 and 2) has a pressure control valve on the water supply and a metering valve on the chemical supply. The Multi Nozzle Lances (MNLs - Zone 3) have a slightly different arrangement. The MNLs have a permanently set water pressure control valve with a reagent flow control valve. This supplies mixed reagent to all four MNLs. Each MNL has its own flow control valve on the IZM to meter the mixed reagent.

Mixed chemical leaves the IZM and travels to the zone distribution modules, where the mixed chemical is metered to each injector. The distribution modules also regulate the air supply to all zones.

Liquid and air are pre-atomized in a mixing chamber and delivered into the flue gas through an air-cooled lance. The spray shape and direction are controlled by a selection of nozzle tips. The SNCR injectors have been carefully characterized for droplet size distribution as a function of liquid flow rate and atomizing air pressure. All wall injectors are placed on retract mechanisms that automatically insert and retract the tips of the injectors through the boiler wall ports. Each Zone of injectors is independently controlled, and is placed into service based on boiler load and furnace temperature.

Zone 3 has four multi-nozzle lances that are ~25 feet long. Two forward lances located within the platen superheaters have five nozzle pairs that are oriented to spray horizontally. The other two lances located ahead of secondary superheater have eleven nozzle pairs spraying vertically. The lances are cooled with condensate water that is returned back to the deaerator. The MNLs are designed to create small droplets for rapid evaporation and maximum coverage and are equipped with a modified soot-blower retract mechanism. Each MNL distribution module is equipped with flow, pressure and temperature sensors that provide signals to a PLC-based master control module. Within the PLC, safety interlocks are programmed, and the flow and temperature alarm points are set. The PLC automatically retracts the lances if any of the conditions are not met.

An optical furnace temperature monitor is installed on one of the side-walls of the upper furnace to measure the flue gas temperature. This instrument measures the radiation from ash particles and correlates the readings to flue gas temperature. This signal is used, along with the boiler steam flowrates, to control the SNCR system.

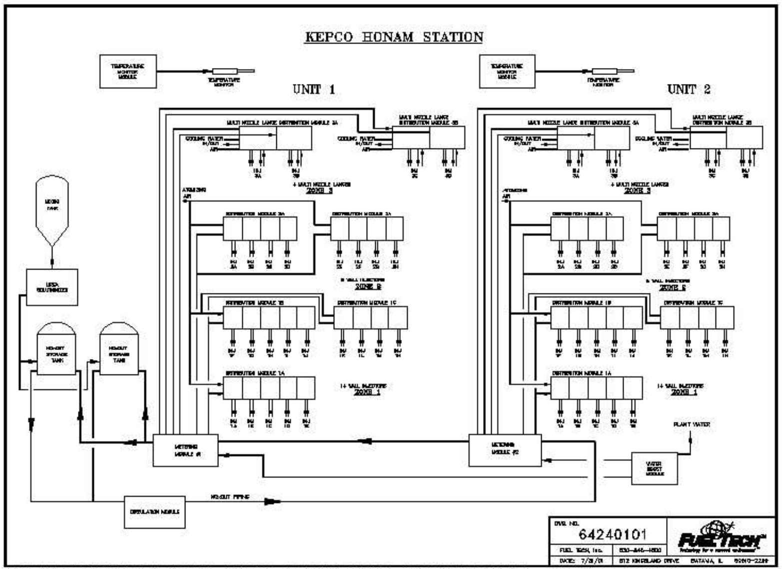

Figure 5 Equipment Layout

START-UP AND OPTIMIZATION TESTS

Following the installation, the equipment check-out began in July 1999. Each module was systematically checked for proper mechanical and electrical operation as well as proper connection to the master control module. The PLC program was modified as required and site-specific parameters and alarm set points were established. Concurrently, the optimization tests were performed in manual and automatic mode to determine the injection parameters and the auto-control table parameters.

Parametric Tests

A series of tests was completed to optimize the injection parameters, and to determine the urea flowrates and the required levels in service for unit operation between 130 MW and 250 MW. After selecting a moderate NSR, the spray pattern was varied to determine the optimum NOx reduction achievable from each level. The reagent flowrate was then varied to determine the chemical utilization and NH_3 slip. Finally, multilevel injection was tested. Simultaneous injection from multiple levels often improves the process performance through increased reagent distribution, and consequently, better utilization. These tests were run at 130 MW, 180 MW and 250 MW.

180 MW to 250 MW

The droplet size distribution and chemical flowrates were optimized for level 2 wall injectors and level 3 lances. The wall injectors used fairly large droplets but the optimum droplet size was significantly smaller for the forward lances and was even finer for the rear lances. As shown in Figures 1 and 4, the forward lances spray into a hotter zone and a wider flue gas path than the rear lances. Since the tube spacing in the platen superheaters is twice the spacing in the secondary superheaters, bigger droplets were generated from the forward lances than the rear lances. When possible, larger droplets are preferred because they penetrate further into the flue gas path thus improving reagent distribution. Fine droplets are generated from rear lances for rapid evaporation.

The level 3 lances provided excellent reagent distribution within the proper temperature range at full load. As the load decreased, ammonia slip increased due to decreasing flue gas temperature near the rear lances while the temperature at level 2 was still optimum. Thus, the reagent flow to level 3 was reduced, and it was biased more towards level 2. At full load, the reagent flowrate was split evenly between levels 2 and 3, but only 30% of the total reagent was sent to level 3 at 180 MW.

130 MW to 180 MW

The wall injectors at levels 1 and 2 were used at loads between 130 and 180 MW. Level 3 lances were retracted at loads below 180 MW. Starting with only 30% of the reagent flow to level 1, the flow increased to 70% at 130 MW.

PERFORMANCE TESTS

Two sets of performance tests were completed as required by the contract. The first performance test was performed in September 1999 at low load (130 MW) and high load (250 MW) while the second test was completed in April 2000. Per contract, the SNCR system operated continuously in automatic mode between the two tests. The performance tests followed the procedure prepared by KHIC and approved by KEPCO. Using ports on a duct between an ID fan and the stack, NOx, O_2, and flue gas volume were measured before and during the chemical injection while holding all boiler parameters constant. Ammonia was measured using economizer outlet ports during the urea injection. The flue gas flowrate, baseline NOx, and urea flowrate were used to calculate the normalized stoichiometric ratio (NSR). The full load test summary is shown in Table 1.

	Unit #1		Unit #2	
	Test 1	Test 2	Test 1	Test 2
Load, MW	250	250	250	250
Baseline NOx, ppm(@ 6% O_2)	462	384	416	333
Controlled NOx, ppm(@ 6% O_2)	271	230	244	208
NSR	1.1	1.1	1.1	1.1
NOx Reduction (%)	41.4	40.1	41.4	37.4
NH_3 Slip, ppm(@ 6% O_2)	9.8	2.6	4.0	2.9

Table 1. Performance Test Summary

The requirements of 40% NOx reduction from a baseline NOx of 400 ppm or higher, an NSR of 1.1, and NH_3 slip of less than 15 ppm, were met, as shown above. At a baseline NOx of less than 400 ppm, the reduction requirement decreased proportionally to 33% at 300 ppm. Thus, the target was only 36 % NOx reduction for Test 2 on Unit #2. At 130 MW, the SNCR system easily achieved the requirements during the first performance test, providing reductions of 46% and 44% for each unit, respectively, with less than 10 ppm NH_3 at NSR of 1. The plant omitted the 130 MW test for the second performance test.

Indicative of low fuel sulfur and controlled ammonia slip, the pressure drop across the air heaters remained relatively constant and no evidence of air pre-heater fouling has been observed.

CONCLUSIONS

The installed urea-based SNCR systems on Unit #1 and Unit #2 at KEPCO’s Honam Station have met all the requirements. The systems were designed, fabricated, installed, and tested within the tight schedule dictated by the plant and within the available plant space. Ports were installed during an annual scheduled outage and no other special outage was required to install the system. The SNCR systems have been in operation for the past two years and no evidence of air pre-heater fouling from ammonia slip has been observed during this time.